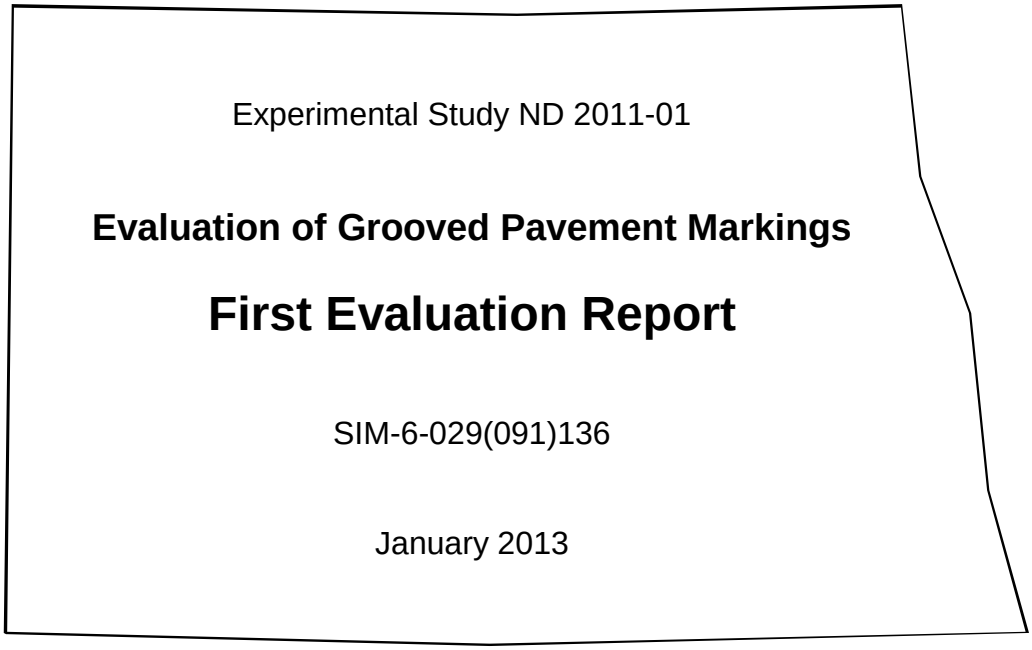
NORTH DAKOTA
DEPARTMENT OF TRANSPORTATION

MATERIALS AND RESEARCH DIVISION



Experimental Study ND 2011-01

Evaluation of Grooved Pavement Markings

First Evaluation Report

SIM-6-029(091)136

January 2013

Prepared by

NORTH DAKOTA DEPARTMENT OF TRANSPORTATION
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Matthew M. Luger

Disclaimer

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U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

EXPERIMENTAL PROJECT REPORT

EXPERIMENTAL PROJECT

EXPERIMENTAL PROJECT NO. (1)

STATE	YEAR		NUMBER	SURF
ND	2011	-	01	

CONSTRUCTION PROJ NO (8): SIM-6-029(091)136

LOCATION (28): I-29 Grand Forks County

EVALUATION FUNDING (48)

1	HP&R	3	DEMONSTRATION
2 X	CONSTRUCTION	4	IMPLEMENTATION

NEEP NO. (49):

PROPRIETARY FEATURE? (51): X Yes / No

SHORT TITLE

TITLE (52): Evaluation of Grooved Pavement Markings

THIS FORM

DATE (140): MO. February -- YR. 2013

REPORTING: 1 INITIAL 2 X ANNUAL 3 FINAL

KEY WORDS

KEY WORD 1	KEY WORD 2
145 Wet-Reflective Elements	167 Pavement Marking
KEY WORD 3	**KEY WORD 4**
189 Grooved	211
UNIQUE WORD	**PROPRIETARY FEATURE NAME**
233	255 3M All Weather Pavement Marking

CHRONOLOGY

Date Work Plan Approved	Date Feature Constructed:	Evaluation Scheduled Until:	Evaluation Extended Until:	Date Evaluation Terminated:
277 January 2011	281 Fall 2011	285 Fall 2014	289	293

QUANTITY AND COST

QUANTITY OF UNITS (ROUNDED TO WHOLE NUMBERS) (297)

Groove	151,496
Water-Borne Wet-Refl.	34,479
Water-Borne Control	34,478
Epoxy Wet Refl.	68,136
Epoxy Control	84,480

UNITS (305)

1	X LIN. FT	5	TON
2	SY	6	LBS
3	SY-IN	7	EACH
4	CY	8	LUMP SUM

UNIT COST (*Dollars, Cents*) (306)

$0.50
$0.38
$0.13
$0.54
$0.34

AVAILABLE EVALUATION REPORTS

CONSTRUCTION (315)	PERFORMANCE	FINAL
	X	

EVALUATION

CONSTRUCTION PROBLEMS (318)

1	X	NONE
2		SLIGHT
3		MODERATE
4		SIGNIFICANT
5		SEVERE

PERFORMANCE (319)

1	EXCELLENT
2	GOOD
3	SATISFACTORY
4	MARGINAL
5	UNSATISFACTORY

APPLICATION (320)

1	ADOPTED AS PRIMARY STD.	4	PENDING
2	PERMITTED ALTERNATIVE	5	REJECTED
3	ADOPTED CONDITIONALLY	6	NOT CONSTRUCTED

(Explain in remarks if 3, 4, 5, or 6 is checked)

REMARKS (321)

This project is scheduled to be evaluated for 2 more years.

Form FHWA 1461

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Definitions

Standard Paint - Water-based paint for pavement marking applications conforming to section 880 of the North Dakota Standard Specifications.

Standard Epoxy - Epoxy paint for pavement marking applications conforming to section 880 of the North Dakota Standard Specifications.

3M All Weather Paint (AWP) A high build water based paint manufactured by 3M for use within its wet reflective pavement marking systems.

Standard Glass Beads - Glass beads for pavement marking paint conforming to section 880 of the North Dakota Standard Specifications (1.5 Refractive Index).

3M Optics - A material developed by 3M that provides wet-night retroreflectivity. (Mixture of 1.9 and 2.4 Refractive Index)

3M Elements - A material that consists of 3M optics bonded to a central core. Used to apply wet-night retroreflectivity to liquid markings. (Mixture of 1.9 and 2.4 Refractive Index)

Standard Preformed Patterned Tape (Standard Tape) - A preformed patterned tape conforming to section 880 of the North Dakota Standard Specifications. (1.5 Refractive Index)

3M All Weather Tape - A preformed patterned tape manufactured by 3M with wet reflective properties. (Mixture of 1.9 and 2.4 Refractive Index)

Evaluation of Grooved Pavement Markings

Purpose and Need

The harsh weather conditions of North Dakota demand frequent replacement of pavement markings. Water based pavement markings are replaced every year. Epoxy pavement markings are constructed with the expectation that they will last for 3-5 years when applied to the surface with proper application techniques. However, there is concern that epoxy pavement markings may not last the projected 3 to 5 years primarily because of snow plow activity. Materials and Research developed a study to compare the performance of surface applied epoxy pavement markings and grooved epoxy pavement markings.

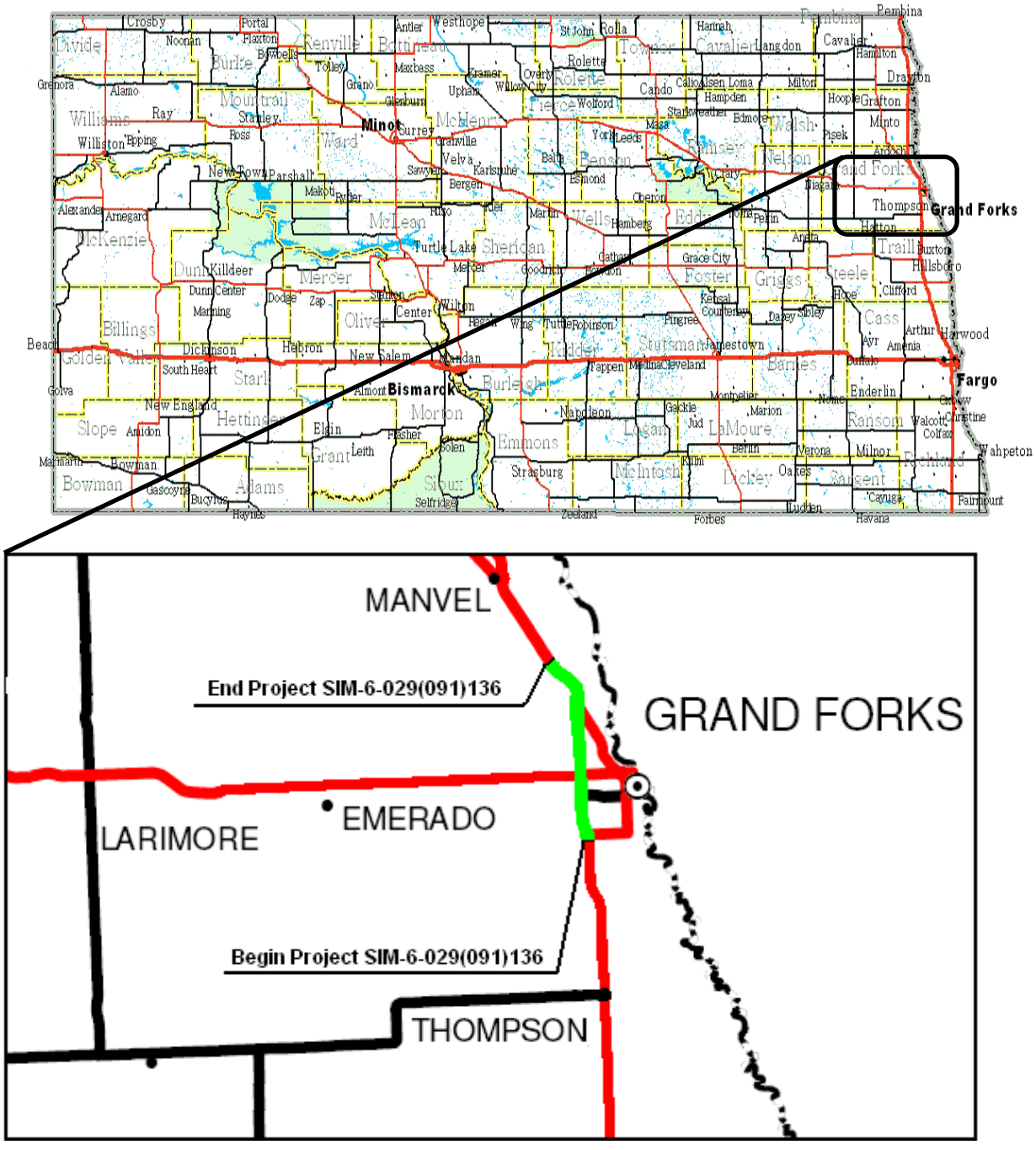
Current NDDOT policy is to construct preformed pattern tape in a groove, while epoxy and water based pavement marking are constructed on the surface of the roadway to save on construction costs. The benefits of constructing pavement markings in a groove is that the marking will be 'protected' from snow plow damage. Possible negatives are that water and dirt may collect in the groove. Due to concerns with water retention in the groove and the proximity to existing wet-reflective research (ND 2010-01), it is proposed to include 3M ALL Weather (AW) markings in this research as well to provide wet-night retroreflectivity.

Objective

The objective of this experimental project is to compare the performance of surface applied epoxy pavement markings and recessed epoxy pavement markings using standard glass beads and 3M Wet Reflective Elements. This project will supplement the previous experimental evaluation of wet reflective markings on project ND 2010-01. This will be accomplished by installing a section of recessed waterborne pavement markings with standard glass beads, 3M Wet Reflective Elements; and a small section of 3M Contrast Tape on the center-line. 3M Contrast Tape has the same retroreflective qualities as 3M AW Tape but has a 1" wide black strip on each side. This modification allows for delineation of the lanes during daylight on a PCC pavement.

Location

NDDOT plans to construct research segments as part of project SIM-6-029(091)136. This project is located near Grand Forks on I-29.



Design

Epoxy pavement markings will be placed on I-29 as part of project SIM-6-029(091)136. This project consists of concrete pavement repair of approximately 20 miles of I-29. The project limits are from RP 136.888 to RP 147.226 in the NB lanes and from RP 136.766 to RP 147.226 in the SB lanes.

The yellow and white edge-lines will be divided into segments and will be constructed according to the following table. Also, a short segment of center-line contrast tape will be constructed in the north bound lane.

Pavement Marking Layout

Segment	Location	Length (feet)	Type	Material	Groove Depth (mils)
1A	RP 136.888 to RP 138 (NB) RP 136.766 to RP 138 (SB)	5,872 (NB) 6,516 (SB)	White and Yellow Edge-line	Water Based Paint with Standard Glass Beads[2]	40 ±5
1B	RP 138 to RP 140 (NB&SB)	10,560	White and Yellow Edge-line	Water Based Paint with 3M AW Optics Series 90	40 ±5
2A	RP 140 to RP 142 (NB&SB)	10,560	White and Yellow Edge-line	Epoxy with Standard Glass Beads[2]	40 ±5
2B	RP 142 to RP 144 (NB&SB)	10,560	White and Yellow Edge-line	Epoxy with 3M AW Elements Series 70E	40 ±5
3A	RP 144 to RP 146 (NB&SB)	10,560	White and Yellow Edge-line	Epoxy with Standard Glass Beads[2]	N/A[1]
3B	RP 146 to RP 147.226 (NB&SB)	6,474	White and Yellow Edge-line	Epoxy with 3M AW Elements Series 70E	N/A[1]
4	RP 136.888(NB)	250 ft (25 10’ skip lines)	Center-line	3M 380 AW-5 Preformed Patterned Tape	100 ±10

[1] Test segments 3A and 3B will be surface applied

[2] ‘Standard glass beads’ shall meet section 880.02 of the NDDOT Standard Specifications.

Grooving equipment shall meet the requirements of NDDOT Standard Specification 762.03 B. The construction of the groove shall meet NDDOT Standard Specification 762.04 B6. For the edge-lines the depth of the groove should be modified as follows: Change depth of groove from *100 mils ± 10 mils* to **40 mils ± 5 mils.**

Evaluation Criteria

The project will be evaluated twice annually for 3 years, or until replacement, if it is determined that the condition of the marking warrants replacement before the end of the evaluation period. The project will be evaluated on the following criteria:

- Determine the Coefficient of Retroreflective Luminance (R_L) with an LTL 2000 Retrometer.
    - Retroreflectivity data will be collected at the odd number mile points in each segment.
    - Ten readings will be collected on each edge line type in a dry condition
    - Five readings will be collected on each edge line type in a simulated wet condition according to ASTM E 2177 *Standard Test Method for Measuring the Coefficient of Retroreflected Luminance (R_L) of Pavement Markings in a Standard Condition of Wetness.*
    - Baseline data will be collected 2 weeks after construction according to NDDOT Standard Specification 762.04 E4.
    - Data will be collected each year once after spring rains (approx. May) and once prior to winter snow (approx. October).
- Visual Inspection
    - The project will be examined visually to assess any durability issues, i.e. damage from snow plows.
    - Visual observations will be documented with photographs.
- District Comments
    - Night Evaluation in dry and wet condition.
    - Observation of the retention of debris/water/ice in the groove.

Materials and Research will publish an annual report documenting the observations of this project.

Construction Evaluation

The striping portion of SIM-6-029(091)136 was completed between October 12, 2011 and October 21, 2011. The sub contractor responsible for striping was Swanston Equipment Co. A 3M representative, Jason Elsen, was onsite to ensure proper application of the AW markings. A truck mounted data logging system captured the details of pavement marking application. A summary of the data collected is included in the following tables:

Pavement Marking Application (North Bound)												
Segment	1A		1B		2A		2B		3A		3B	
Type	Control		All Weather		Control		All Weather		Control		All Weather	
Material	Paint		Paint		Epoxy		Epoxy		Epoxy		Epoxy	
Color	White	Yellow	White	Yellow	White	Yellow	White	Yellow	White	Yellow	White	Yellow
Liquid Application Rate (ft/gal)	300.3	297.3	188.7	190.5	238.9	247.5	231.9	240.9	238.7	247.5	231.9	240.9
Thickness Wet (Mils)	16.0	16.2	25.6	25.2	20.2	19.4	20.8	20.0	20.2	19.4	20.8	20.0
Standard Glass Bead Application Rate (lbs/gal)	6.3	6.3	4.8	4.1	37.8	21.9	31.2	31.5	37.8	21.9	31.2	31.5
3M AW Elements Application Rate (lbs/gal)	-	-	2.1	2.1	-	-	4.9	5.1	-	-	4.9	5.1

Application (South Bound)												
Segment	1A		1B		2A		2B		3A		3B	
Type	Control		All Weather		Control		All Weather		Control		All Weather	
Material	Paint		Paint		Epoxy		Epoxy		Epoxy		Epoxy	
Color	White	Yellow	White	Yellow	White	Yellow	White	Yellow	White	Yellow	White	Yellow
Liquid Application Rate (ft/gal)	298.1	294.5	188.6	196.0	238.9	247.5	231.9	240.9	238.9	247.5	231.9	240.9
Wet Mils Thickness	16.1	16.3	25.5	25.9	20.2	19.4	20.8	20.0	20.2	19.4	20.8	20.0
Standard Glass Bead Application Rate (lbs/gal)	6.2	6.2	4.4	4.7	37.8	21.9	31.2	31.5	37.8	21.9	31.2	31.5
3M AW Elements Application Rate (lbs/gal)	-	-	2.2	2.2	-	-	4.9	5.1	-	-	4.9	5.1

The application of the paint and epoxy was completed without any issues that would impact long term performance. However, the existing surface of the roadway may impact the effectiveness of the grooves. The existing roadway is PCC pavement. Prior to installation of the pavement markings, concrete pavement repair (CPR) work was completed. The CPR work included grinding to improve the ride. The grinding operation left a profile in-between passes of the grinder. In many locations, the profile had a ridge or a depression in the path of the stripe, or adjacent to the stripe. As a result the groove depths were inconsistent due to a varying surface profile. Also, in non-grooved segments, the stripe is somewhat protected by the profile left by the grinder.

Evaluation 1 - 2012

Visual Appearance

This project was evaluated on June 5, 2012 and November 11, 2012. The markings are showing signs of distress. Distresses include loss of material (primarily in the water based segments), loss of glass beads, and damage to the 3M AW Elements. There were 3 different types of damage to the 3M AW Elements. Some Elements saw deterioration of the coating around the element that contains the microcrystalline optics. Some of the AW Elements were sheared in half, and some Elements were completely removed. An example of the various types of distress is shown in the Photo 1 below.

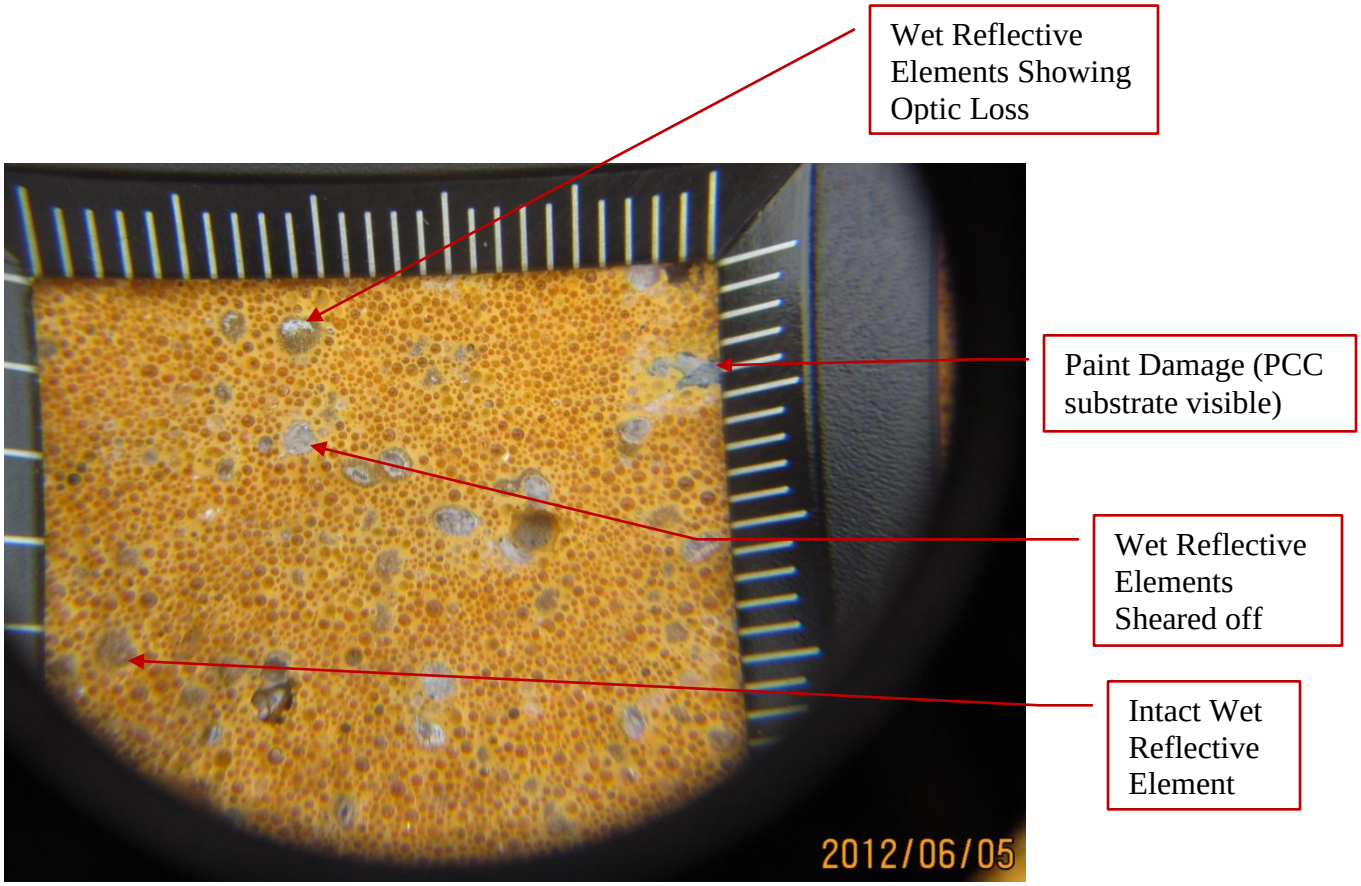


Photo 1: Types of Distress

The distresses did not follow a pattern that was consistent with the grooved and non-grooved segments. The reason that the distress did not correlate to the grooved pattern could be attributed to a few different scenarios. The first is that the 40 +/-5 mil

groove depth may not have been deep enough to protect all the components of the pavement marking. Also, the profile from the grinder left some marking exposed and other marking protected regardless of whether it was in a grooved segment or not. It is evident when looking at the line (and using the Texas Test) that in many locations the groove depths are inconsistent and/or inadequate. The Texas Test is a subjective way to determine the distribution of glass beads using sunlight. It's also visually apparent that some of the non-grooved segments have been somewhat protected by the surface profile. The following photos help to illustrate the conditions on the roadway:

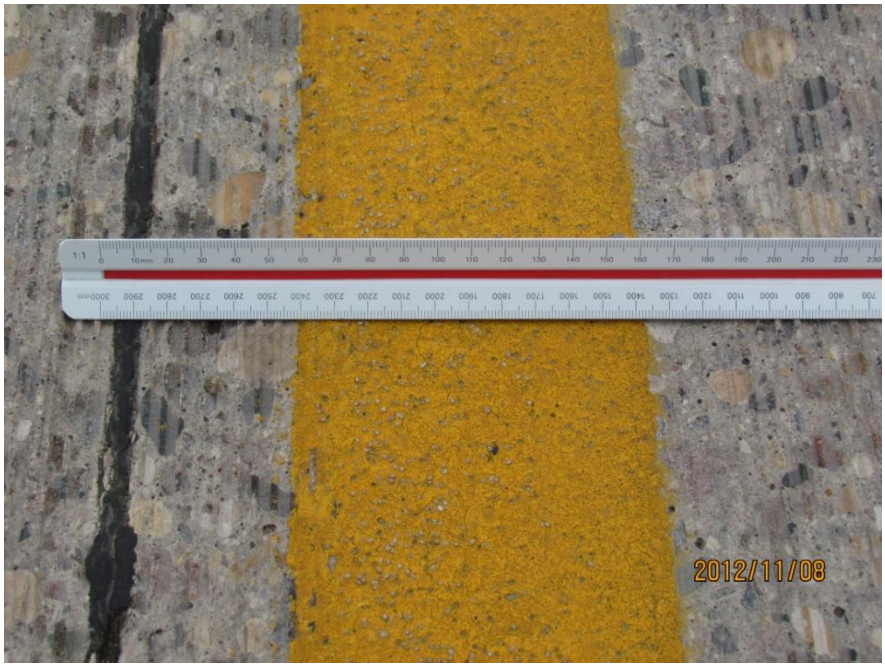


Photo 2: Yellow All Weather Paint with 3M Elements in a Groove in the Southbound Direction

The above photo shows a yellow AW Paint stripe with 3M Elements in a groove. The groove is so shallow that it is difficult to detect. The photo also shows that while the paint is intact, the larger 3M Elements have been sheared in half.

Photo 3: Surface Applied White Epoxy with Standard Glass beads in the Northbound Direction

Photo 3 above shows a ridge in the middle of the stripe left by the grinder. This ridge created a line that had a varying amount of protection from snow plow damage.

Retroreflectivity

Retroreflectivity data has been collected on three separate occasions when this report was written. The same standards have been used for each data collection. Retroreflectivity data was collected from the middle of each test segment. Ten readings were collected on each line type in a dry condition. Five readings were collected in a wet-recovery condition according to ASTM E 2177.

Initial retroreflectivity data was collected within one month after application. Retroreflectivity data was collected again in the spring after one winter and in the following fall. The average data for each segment is summarized in the following charts:

ND 2011-01 - I-29 Northbound White Edge-line												
Date Tested	Water Based Paint (40 +/-5 mil Groove)				Epoxy (40 +/-5 mil Groove)				Epoxy (Surface Applied)			
	Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements	
	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*
11/3/2011	379	2	512	180	343	22	566	123	348	57	627	222
6/5/2012	296	1	188	13	80	0	348	9	129	7	241	46
11/8/2012	306	1	96	7	88	1	176	8	84	8	188	25

*The wet condition above corresponds to a 'wet-recovery' condition as described in ASTM E 2177

ND 2011-01 - I-29 Northbound Yellow Edge-line												
Date Tested	Water Based Paint (40 +/-5 mil Groove)				Epoxy (40 +/-5 mil Groove)				Epoxy (Surface Applied)			
	Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements	
	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*
11/3/2011	203	5	158	45	200	14	355	139	219	23	395	269
6/5/2012	162	4	94	6	172	5	295	37	106	4	241	46
11/8/2012	97	1	72	1	109	4	257	43	141	9	184	11

*The wet condition above corresponds to a 'wet-recovery' condition as described in ASTM E 2177

ND 2011-01 - I-29 Southbound White Edge-line												
Date Tested	Water Based Paint (40 +/-5 mil Groove)				Epoxy (40 +/-5 mil Groove)				Epoxy (Surface Applied)			
	Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements	
	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*
11/3/2011	349	4	576	200	318	23	634	32	314	31	519	201
6/5/2012	181	2	222	37	275	8	313	6	206	19	219	10
11/8/2012	156	1	171	8	79	0	241	3	148	4	182	5

*The wet condition above corresponds to a 'wet-recovery' condition as described in ASTM E 2177

ND 2011-01 - I-29 Southbound Yellow Edge-line												
Date Tested	Water Based Paint (40 +/-5 mil Groove)				Epoxy (40 +/-5 mil Groove)				Epoxy (Surface Applied)			
	Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements		Standard Glass Beads		3M AW Elements	
	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*	Dry	Wet*
11/3/2011	206	19	258	72	241	43	424	202	186	14	463	252
6/5/2012	120	2	152	37	203	14	298	42	99	1	200	28
11/8/2012	112	23	108	22	96	5	276	96	73	2	174	43

*The wet condition above corresponds to a 'wet-recovery' condition as described in ASTM E 2177

Cost

The following table is a breakdown of the costs of each material. Note that for this project the 'PAVEMENT MARKING GROOVE' was a separate bid item.

Bid Item	PAVEMENT MARKING GROOVE	EPOXY PVMT MK 4IN LINE	EPOXY PVMT MK 4 IN LINE - WET REFLECTIVE	PVMT MK PAINTED 4 IN LINE	PVMT MK PAINTED 4 IN LINE - WET REFLECTIVE
Quantity (LF)	151,496	84,480	68,136	34,478	34,479
Price/LF	$0.50	$0.34	$0.54	$0.13	$0.38
Total	$75,748.00	$28,300.80	$36,452.76	$4,309.75	$13,102.02

Summary

After one winter the pavement markings on this project appear to be showing signs of distress. Distresses observed include minor loss of paint, minor loss of glass beads, minor loss of 3M AW Elements, and damage to 3M AW Elements. The distresses do not follow a consistent pattern.

The retroreflectivity also has a lot of variability between each section. After one winter 16 of 24 segments have a dry retroreflectivity above 100 mcd/m^2/lux. After one winter only 1 segment has a wet recovery retroreflectivity above 50 mcd/m^2/lux.

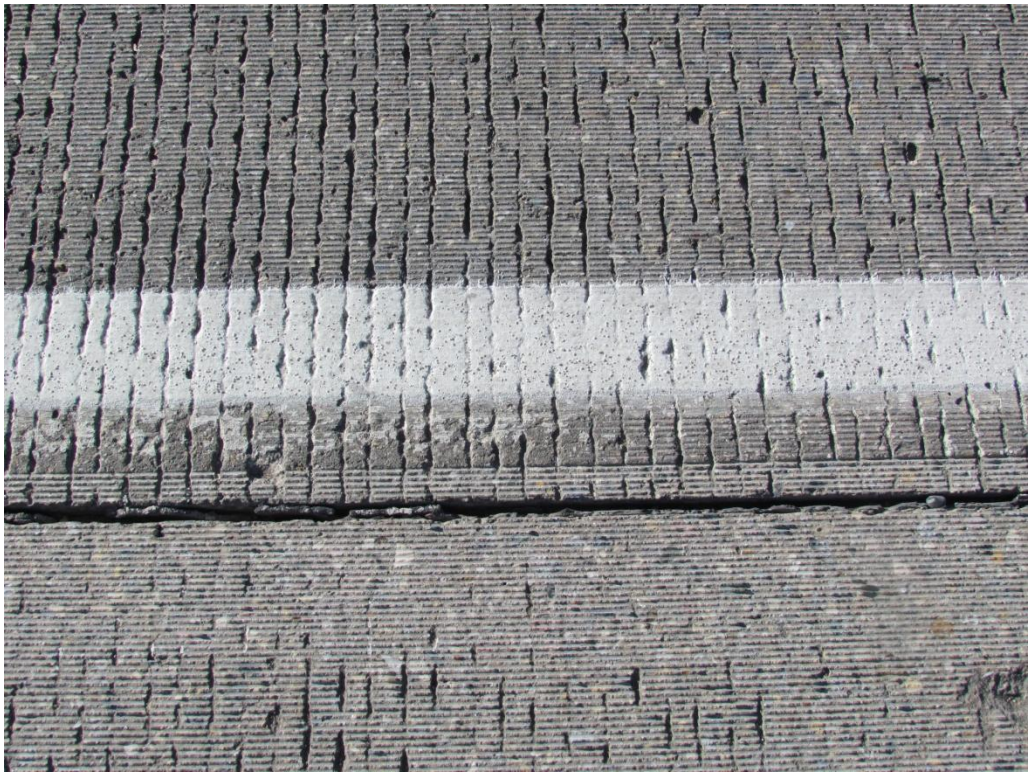
The randomness of the distresses may be attributed to the uneven profile left as a result of the grinding operation. This uneven profile may have helped protect the surface applied segments from snow plow damage. Also, the 40 +/- 5 mil groove depth may have been too shallow to fully protect the 3M AW Elements from snow plow damage. New standards form the 3M Manufacturer state that pavement marking with AW Elements should have a groove depth of 60 +/- 5 mils.

The markings continue to perform at an acceptable level, therefore this project will be re-evaluated in the spring of 2013.

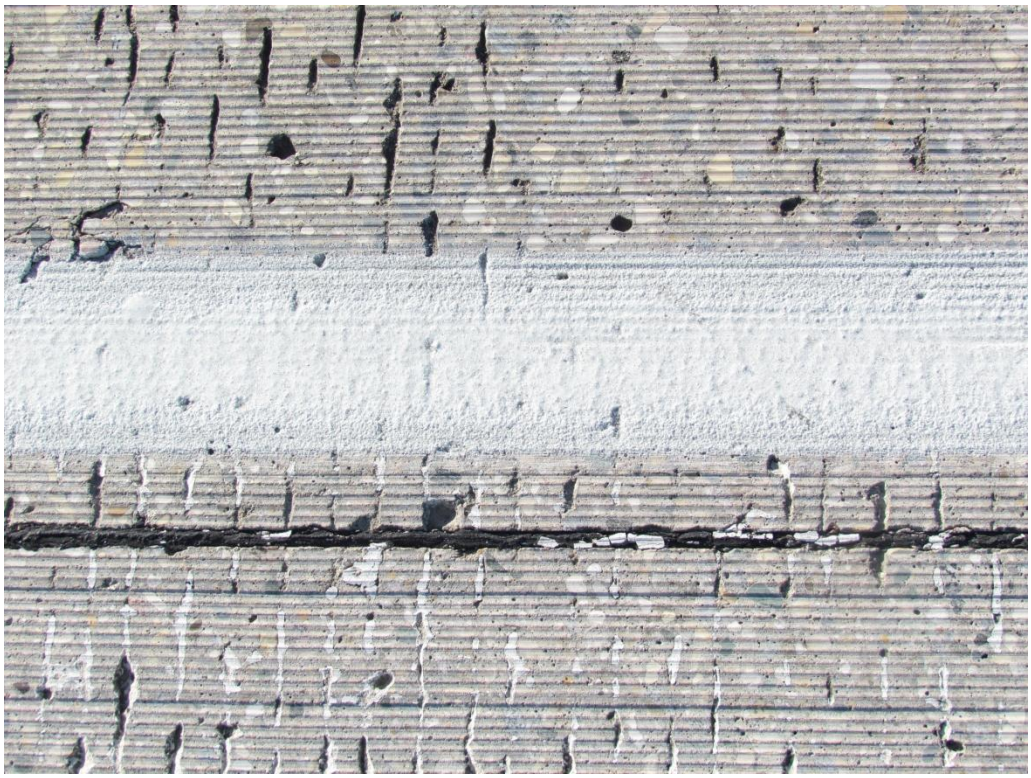
Appendix A - Construction Photos

Segment 1A - Grooved Paint with Standard Glass Beads

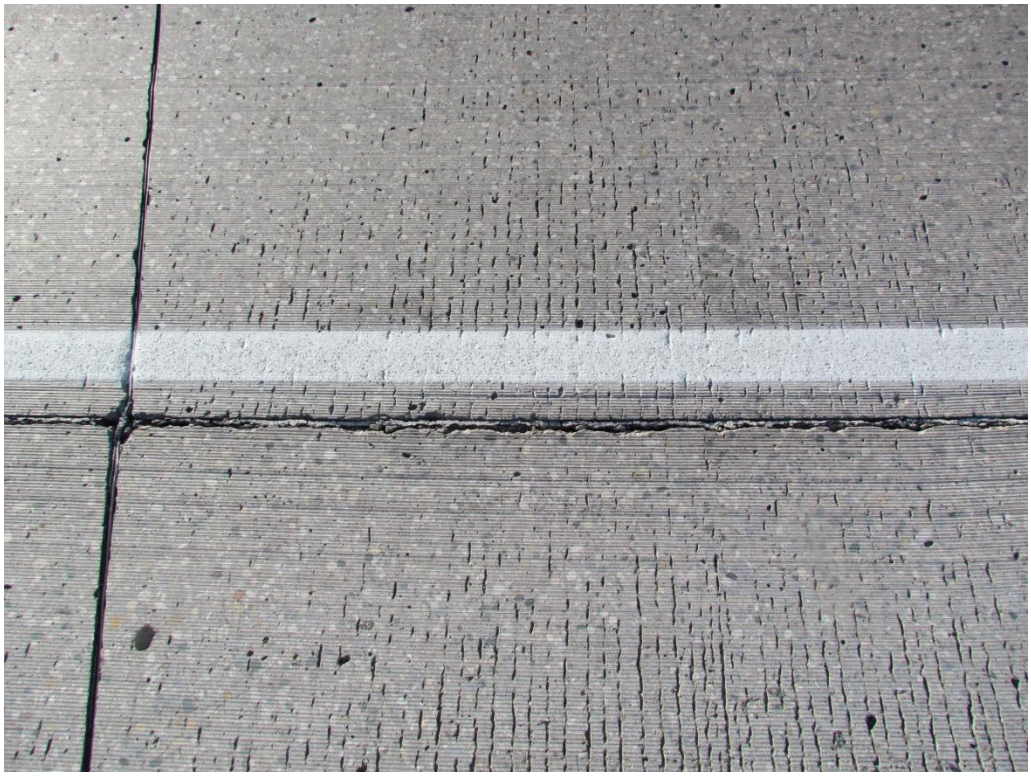
Segment 1B - Grooved Paint with 3M AW Elements



Segment 2A - Grooved Epoxy with Standard Glass Beads

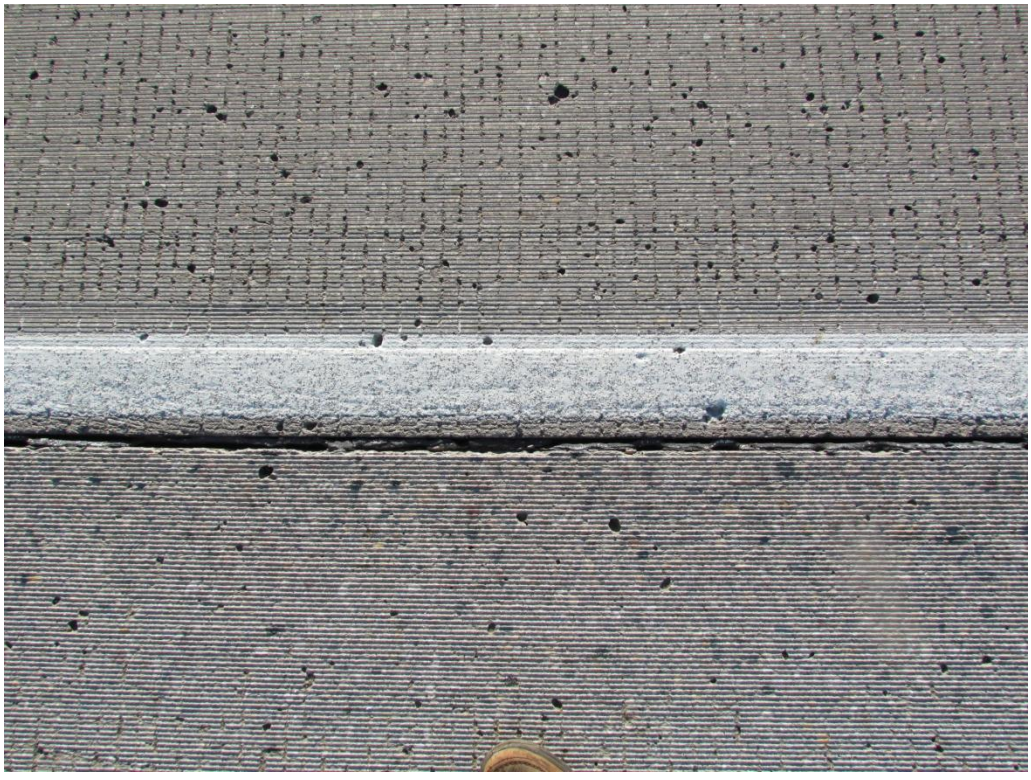


Segment 2B - Grooved Epoxy with 3M AW Elements



Segment 3A - Surface applied Epoxy with Standard Glass Beads

Segment 3B - Surface applied Epoxy with 3M AW Elements



Appendix B - First Evaluation (Fall 2012)

Segment 1A - North Bound White Grooved Paint with Standard Glass Beads

Segment 1B - North Bound White Grooved Paint with 3M AW Elements

Segment 2A - North Bound White Grooved Epoxy with Standard Glass Beads

Segment 2B - North Bound White Grooved Epoxy with 3M AW Elements

Segment 3A - North Bound White Surface applied Epoxy with Standard Glass Beads

Segment 3B - North Bound White Surface applied Epoxy with 3M AW Elements

Segment 1A - South Bound White Grooved Paint with Standard Glass Beads

Segment 1B - South Bound White Grooved Paint with 3M AW Elements

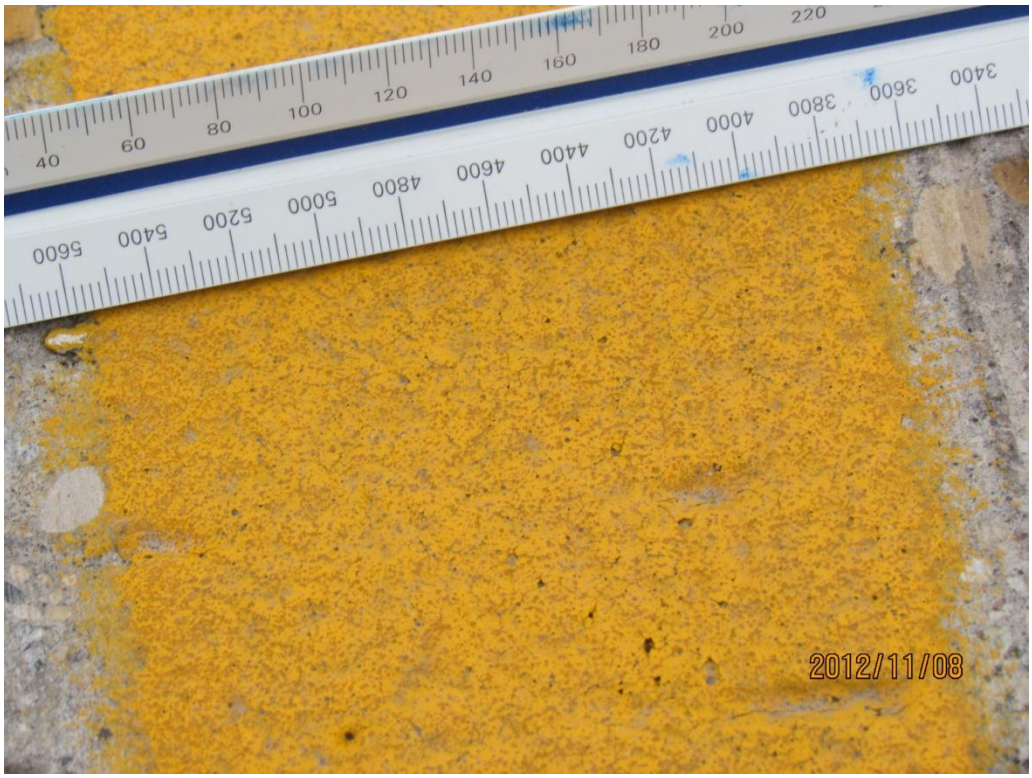
Segment 2A - South Bound White Grooved Epoxy with Standard Glass Beads

Segment 2B - South Bound White Grooved Epoxy with 3M AW Elements

Segment 3A - South Bound White Surface applied Epoxy with Standard Glass Beads

Segment 3B - South Bound White Surface applied Epoxy with 3M AW Elements

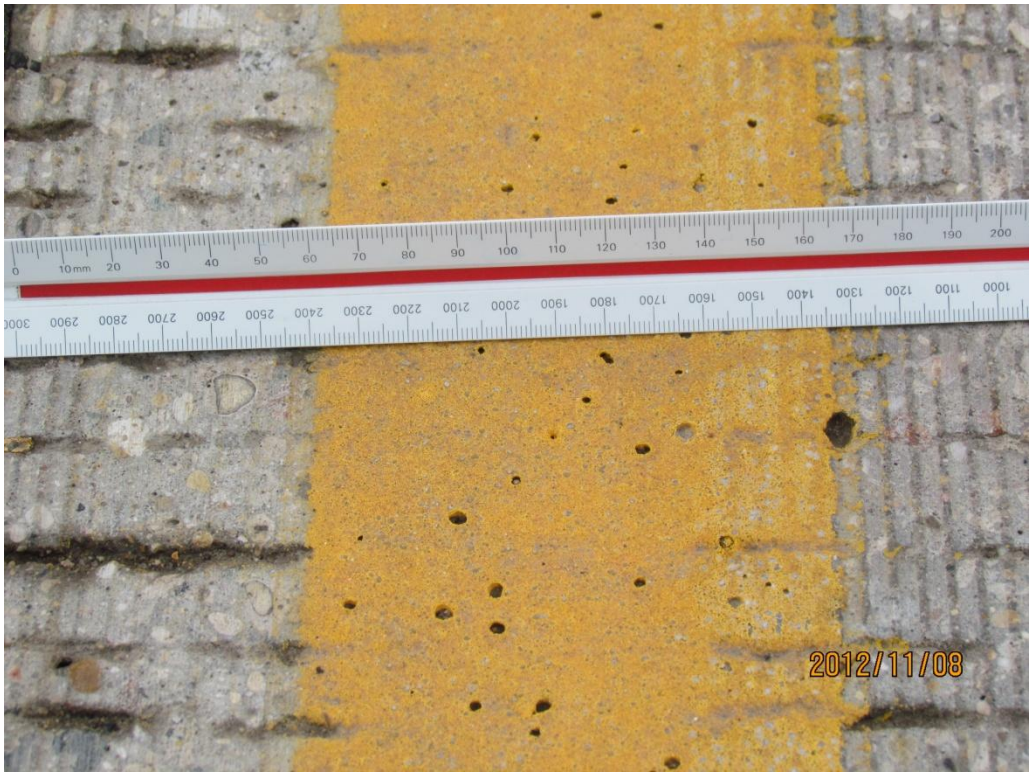
Segment 1A - North Bound Yellow Grooved Paint with Standard Glass Beads



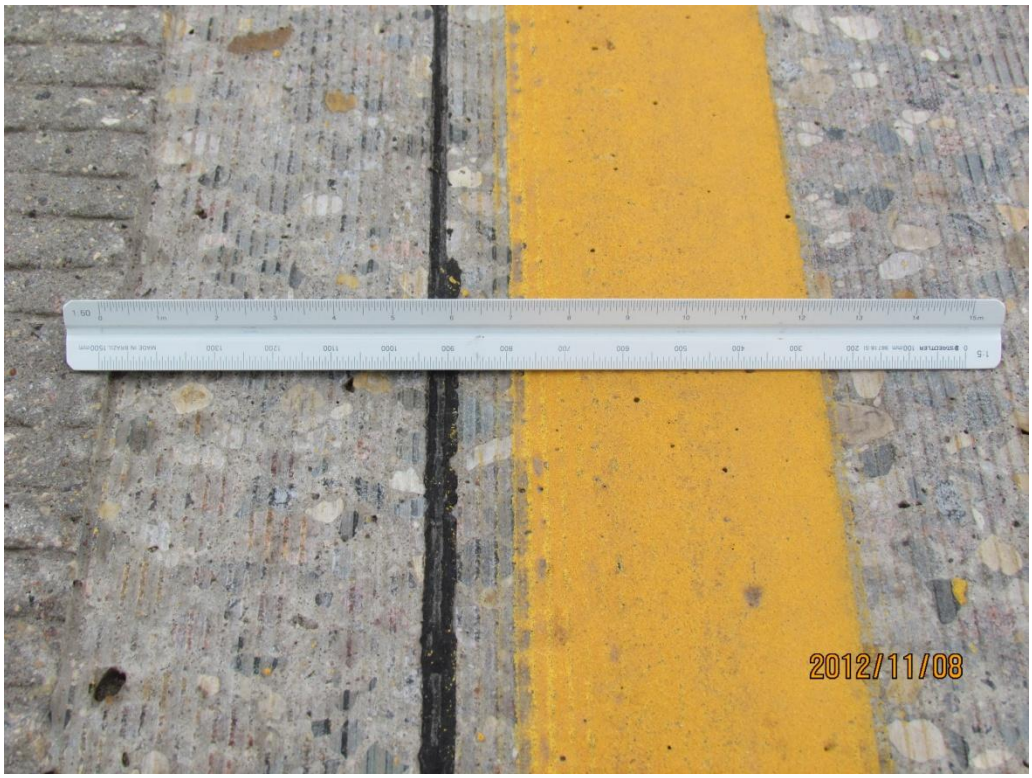
Segment 1B - North Bound Yellow Grooved Paint with 3M AW Elements

Segment 2A - North Bound Yellow Grooved Epoxy with Standard Glass Beads

Segment 2B - North Bound Yellow Grooved Epoxy with 3M AW Elements



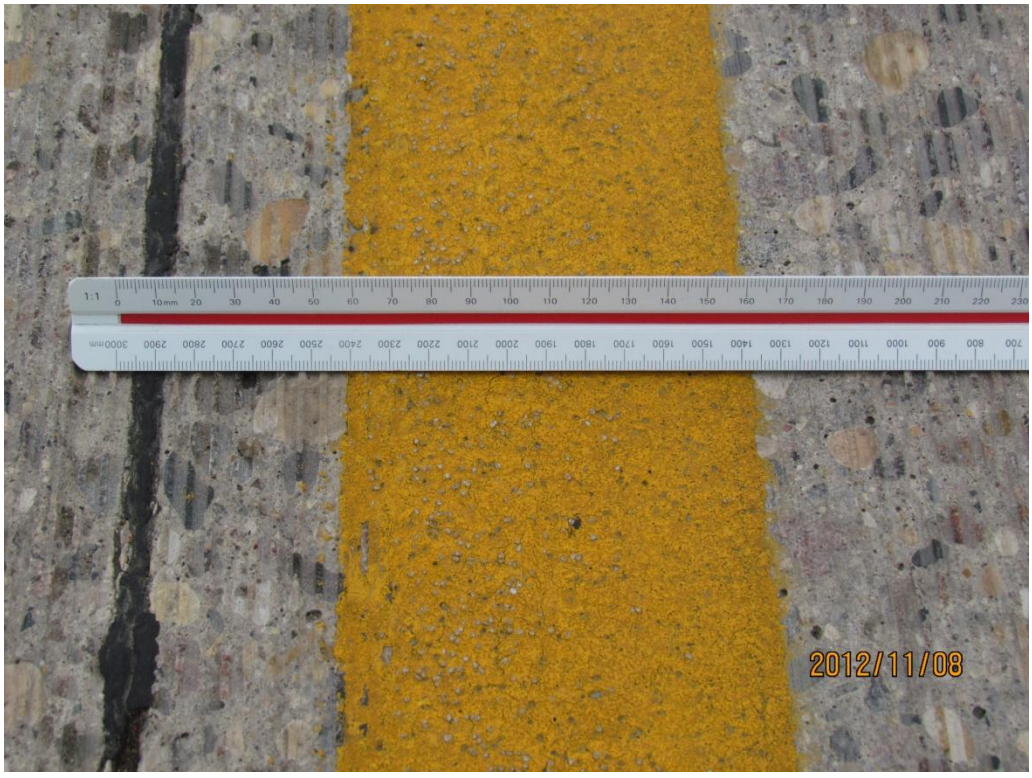
Segment 3A - North Bound Yellow Surface applied Epoxy with Standard Glass Beads



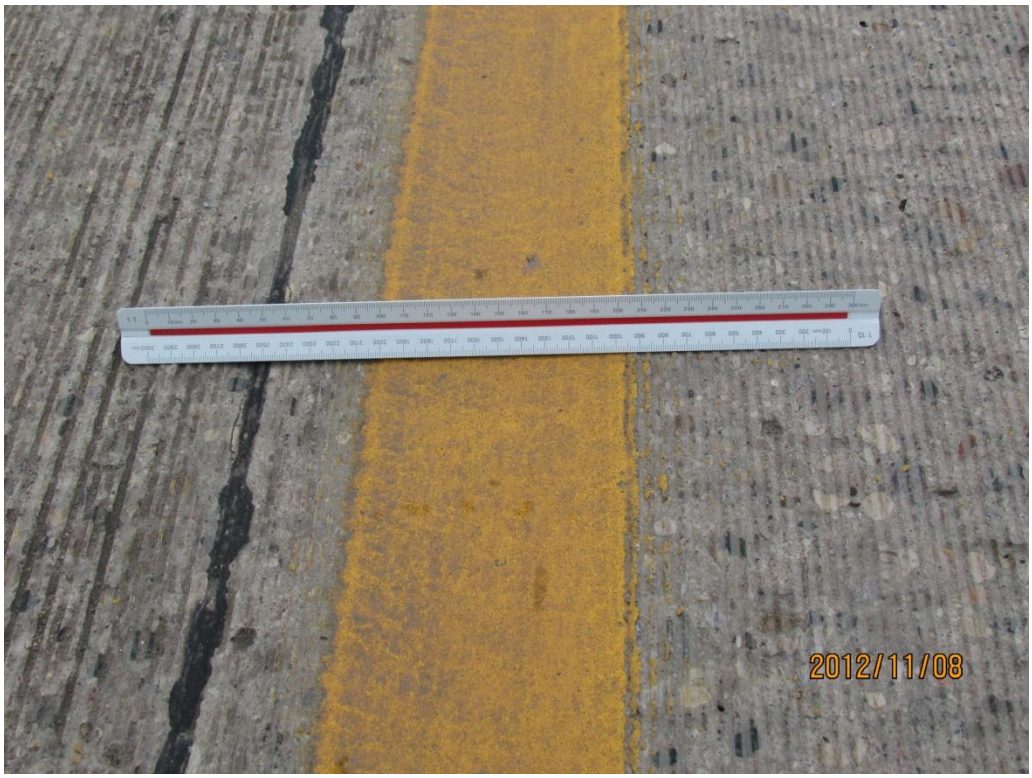
Segment 3B - North Bound Yellow Surface applied Epoxy with 3M AW Elements

Segment 1A - South Bound Yellow Grooved Paint with Standard Glass Beads

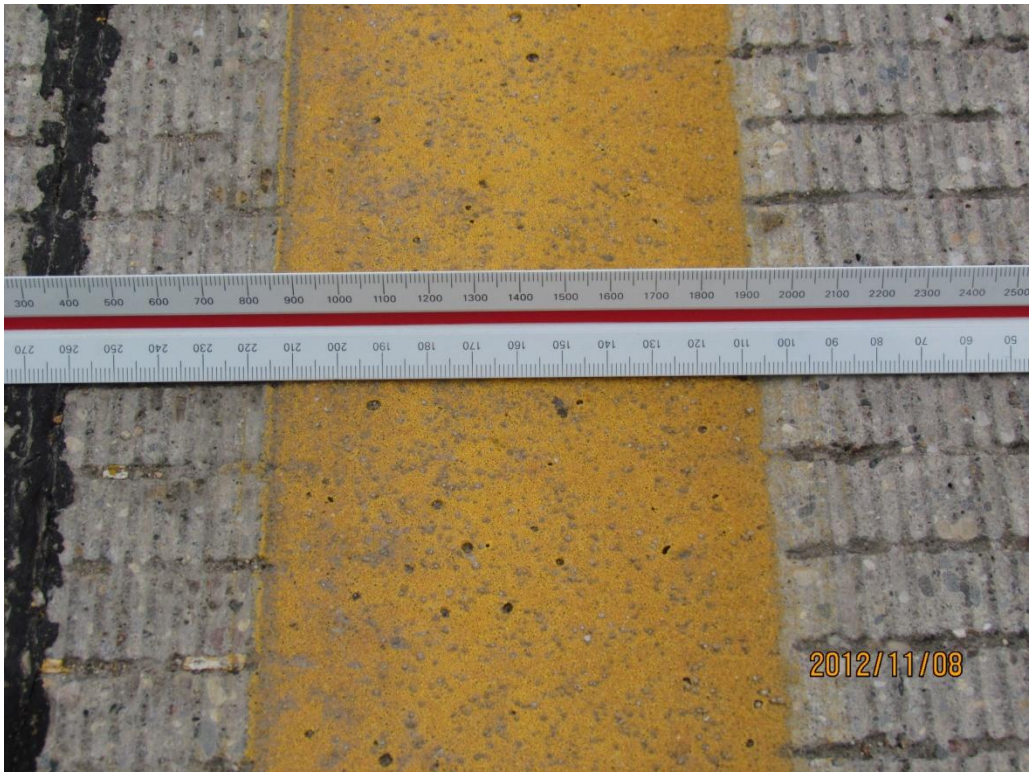
Segment 1B - South Bound Yellow Grooved Paint with 3M AW Elements



Segment 2A - South Bound Yellow Grooved Epoxy with Standard Glass Beads



Segment 2B - South Bound Yellow Grooved Epoxy with 3M AW Elements



Segment 3A - South Bound Yellow Surface applied Epoxy with Standard Glass Beads

Segment 3B - South Bound Yellow Surface applied Epoxy with 3M AW Elements